Advanced Propulsion Research

Advanced Propulsion Research - Magnets

The materials research for lightweight magnets that will have applications in magnetic confinement and as guideways in nozzles will be extensive. Lightweight magnets are absolutely enabling to a wide range of breakthrough propulsion systems, including plasma thrusters, fusion propulsion, electric thrusters, and magneto-hydrodynamic (MHD) accelerators. In the long term, they are required for anti-matter containment in systems that will utilize advanced physics principles. The challenge is to achieve low weight, large volume, high field magnets, and requisite improvements in the strength of associated structural support materials. Common magnet systems have specific energies ($E_{sp} = \frac{B^2}{2\mu} \times \frac{V}{m}$) on the order of 5 kilojoules per kilogram where B is the magnetic flux density, V is the enclosed working volume, μ is the magnetic permeability and m is the mass. The most advanced laboratory scale magnets presently can develop specific energies around 30 kilojoules per kilogram. The advanced propulsion systems noted above require significant advances. The specific energy requirements for many advanced propulsion systems is up to 1,000 kJ/kg. In order to achieve the desired specific energy, advances are needed to produce materials to make lightweight confinement structures capable of withstanding the enormous Lorentz force exerted by the magnet.

One of the primary considerations for superconducting magnet system design is not only the weight of the magnet and cryogenic container, but the total weight of the combined magnet, cryogenics, and electrical power supply to energize the magnet must be taken into account. In addition, while it would be desirable to operate a superconducting magnet in the persistent current mode so that no power would have to be supplied once it is energized, this situation may not be achievable on a continuous basis in practice. Because the field produced by the magnet may be used for plasma confinement, there will be both steady and transient fields acting on the coil causing both field changes and possible quenching of the superconducting material. In excess of 100 amps may be required to fully energize the coil and the weight of a standard DC supply that can provide this much current may be prohibitive. Therefore, work to perfect methods of making zero-resistance connections between conductors needs to be done to eliminate the need for large DC power supplies. With zero resistance joints a lightweight superconducting flux-pump could be used to energize the magnet. This type of supply can be operated from low voltage, low current power supplies with a feedback system that will correct the field produced by the coil.

Current carriers developments are not limited to superconductors. For example, conductor resistance produces heat and is a major problem to dissipate in space. Copper is normally used as the shunting material surrounding superconductors to handle the current in the event of a quenching of the superconducting core. The finite resistance of copper could result in the uncontrolled release of huge quantities of stored energy during a quench. Substitution of lower-mass, high-conductivity, high-strength materials for the copper, such as carbon nanotubes and carbon/carbon structures is viewed as a means of improving performance for flight hardware. Limitations on carbon nanotube length and the untried approach to surrounding superconductors with carbon to handle quench events are limitations to the development of flight magnets. Polymers and composites are potentially enabling to the development of such systems, but presently have not been applied for such applications. Carbon nanotubes and fibers may be a solution for reinforcement and as a quench path material. The study of continuous, high strength superconducting nanotubes may be of interest. Additionally, there is a need to increase the standard electrical conductivity of high specific strength quench path materials to conduction values similar at least that of silver.

There are several design considerations for materials used to construct superconducting coils that can operate in a persistent current mode and for flux pumps to power them up. Materials science research is needed to develop: superconducting zero resistance electrical connections in high temperature superconducting wires, low density – high strength forms on which to wind the coils, materials to be used in lightweight shielding of the coils against pulsed magnetic fields during plasma containment, materials for light weight shielding of the coils against high temperatures generated in plasmas, materials for light weight shielding of the coils against nuclear radiation damage from reactions in the plasma, and materials for a lightweight power supply.

Advanced Propulsion Research – Electrodes and Grids

Magnetohydrodynamic (MHD) systems are of interest to support missions that require a lifetime of 12 years. Current systems have grids with lifetimes on the order of hours, with a surface area of 1-2 m^2. Systems need to be able to survive high temperatures, high current flow (10kA), and severe radiation environments. Improvements in electrode design could improve performance and lifetime.

Advanced Propulsion Research – Radiators/heat pipes

The goal is to attain ≥25% improvement in the efficiency of sodium vapor heat pipes. The minimum operating temperature is to be 1200K. Therefore, pipe material or coatings compatible with sodium vapor inside the pipe operating at 1200K is required. Lithium is also under consideration as a working fluid. Layered structures for pipe or coatings inside tube and components can be considered. Metal matrix composite (MMC) represent the state of the art, with 1 atmosphere, 1200K – molybdenum heat pipe with sodium vapor coolant system, operated with non turbulent flow. Systems with Mo tubing have been developed but are considered too heavy. Current radiator specific mass is 5 kg/ m^2; the goal is 4 kg/m^2. Future systems require lightweight, high conductivity high-temperature alloy or material that is resistant to corrosion and micrometeoroid impacts--self healing materials are of interest.

Materials science research topics include:

1. The design of a lightweight multi-layered thin-wall tubing with an interior coating in order to minimize weight and maximize thermal efficiency. This can include research on the substrate, coatings, and their dimensions and properties in order to obtain the desired performance from the system

2. The development of the best approaches for coating the inside diameter of a thin-wall tubing in order to produce the desired multi-layered structure.
3. The determination of the thermal, corrosion, chemical compatibility and mechanical properties (thermal conductivity, corrosion rate, thermal stability, impact resistance, high-temperature strength, creep resistance, thermal and thermomechanical fatigue resistance, etc) of the heat pipe materials during high temperature service is space.
4. Studies to determine methods to reduce the mass of fins and wicks.
5. Fundamental studies of materials that possess high emittance and the fundamental properties that cause a material to have a high emittance.